hardware

MDPI

Article

Low-Cost Open-Source Electric Needle Incinerator for Biomedical Waste Management

Dely Bravo-Donoso, Yadhyra Ayo, Abel Remache * and Tatiana Freire-Rosero

Facultad de Ingeniería y Ciencias Aplicadas, Universidad Central del Ecuador, Quito 170902, Ecuador; dnbravo@uce.edu.ec (D.B.-D.); ymayop@uce.edu.ec (Y.A.); tefreire@uce.edu.ec (T.F.-R.)
* Correspondence: apremache@uce.edu.ec

Abstract

The safe disposal of sharps, particularly acupuncture and dry needling needles, remains a challenge in clinical and therapeutic environments, where inadequate management increases the risk of occupational injuries and infections. Commercial needle disposal devices are often costly, non-portable, and closed-source, limiting their adoption in small clinics and low-resource contexts. This work presents the design, construction, and validation of an open-source electric needle incinerator developed as a low-cost, safe, and reproducible alternative for biomedical waste management. The device was designed using accessible materials, 3D-printed components, and standard electronic parts, ensuring ease of replication. Detailed build and operating instructions are provided, to facilitate reproduction and future development of the system. Validation tests confirmed that the prototype incinerates individual needles in 3–5 s, processing typical sessions of 5–20 needles without performance degradation. Safety was ensured through thermal insulation, protective casing, and compliance with international standards. The fabrication cost of approximately 199 USD represents a reduction of over 65% compared to commercial devices priced at 600–1500 USD. By openly releasing the design, this contribution supports the hardware community with a replicable solution that enhances occupational safety, reduces costs, and fosters innovation in therapeutic and educational contexts.

Keywords: open-source hardware; needle incinerator; biomedical waste management; additive manufacturing; occupational safety

1. Introduction

The safe management of sharp medical waste has been consistently identified as a global health challenge [1,2]. The World Health Organization (WHO) estimates that unsafe handling of sharps contributes significantly to occupational injuries and the transmission of bloodborne pathogens such as hepatitis B, hepatitis C, and HIV [3,4]. In therapeutic and outpatient contexts, including acupuncture, physiotherapy, and dry needling [5]. The recurrent use of filiform needles increases the need for effective, accessible, and safe disposal devices [6]. Despite the critical nature of this issue, many healthcare providers, particularly in small clinics and alternative medicine practices, still rely on improvised disposal methods that compromise both occupational safety and environmental protection [7].

Commercially available solutions, such as autoclaves and electric needle incinerators, remain limited in their applicability [8]. Their high costs (300–400 USD), bulky dimensions, and proprietary designs restrict widespread adoption, especially in low-resource environments [9]. Furthermore, most of these devices lack open technical documentation,

Academic Editor: Peter C. Hauser

Received: 31 October 2025
Revised: 1 June 2026
Accepted: 9 June 2026
Published: 11 June 2026

preventing adaptation, repair, or reproduction by practitioners and educational institutions. This gap has led researchers and designers to explore low-cost, portable, and open-source alternatives that can guarantee biosecurity without compromising usability [10,11]. Previous studies have explored electrically assisted needle destruction technologies ranging from compact point-of-use needle destroyers to larger plasma-based biomedical waste treatment systems [12]. Portable electric needle incinerators based on localized resistive heating and electrical arcing have demonstrated the capability to rapidly oxidize metallic needles while reducing risks associated with sharps reuse and accidental needlestick injuries [13]. More advanced plasma-assisted systems have also been investigated for large-scale medical waste treatment, achieving high destruction efficiencies at elevated operating temperatures [14,15].

In this context, the integration of user-centered design approaches becomes particularly relevant. By applying methodologies such as Design Thinking, it is possible to capture the needs of practitioners, identify ergonomic and functional requirements, and translate them into reproducible technical solutions [16]. Previous stages of this research included surveys with healthcare professionals, analysis of typological references, and prioritization of design criteria using Saaty's analytic hierarchy process, which confirmed safety, accessibility, and affordability as the most critical parameters guiding device development.

Based on these challenges, the present study addresses the following research questions: RQ1: Can an open-source electric needle incinerator provide reliable needle degradation performance suitable for outpatient therapeutic environments? RQ2: Is it possible to develop a safe, low-cost, and reproducible biomedical sharps disposal device using additive manufacturing and commercially available components? RQ3: How do key thermal–electrical and geometric design parameters influence the operational performance and safety of the proposed system?

Building upon this foundation, the present work introduces the design, construction, and validation of an open-source electric needle incinerator conceived to address both occupational safety and economic feasibility. Unlike conventional publications that limit hardware descriptions to Supplementary Materials, this study provides complete design documentation, open access to digital files, and detailed validation procedures. The contribution aims to empower the open hardware community with a reproducible device that can be replicated, improved, and adapted for use in outpatient clinics, educational laboratories, and low-resource healthcare contexts.

2. Design

2.1. Working Principle

The proposed device operates through direct resistive heating, a mechanism in which electrical current passing through a conductive element generates heat due to the Joule effect. The system uses a low-voltage, high-current transformer (input 110 V, output 5 V–10 A), selected to safely deliver sufficient power for rapid thermal degradation of fine needles [14].

When the user inserts a needle into the input port, the needle shaft closes the circuit between two copper contact plates located inside the upper section of the device. Copper was selected as the electrode material due to its excellent electrical conductivity and stability under short-duration heating cycles. Once the circuit is closed, electrical current flows through the needle and the contact region, producing intense localized heating by the Joule effect. This temperature increase is sufficient to incinerate the segment of the needle exposed to the heating zone in approximately 3–5 s, as confirmed by functional testing.

To ensure user safety and prevent heat transfer to the external casing, the heating module is mechanically isolated from the 3D-printed ABS enclosure. The system incorporates the following:

- A thermal separation layer;
- Passive ventilation slots;
- A brief activation period that limits heat diffusion.

ABS, with a glass transition temperature of approximately 105 °C and a heat deflection temperature (HDT) of 95–110 °C, remains well below its thermal limits during operation. External surface temperatures measured during testing remained between 34 and 42 °C, demonstrating safe operation and confirming that heat does not build up within the enclosure.

This design ensures efficient needle destruction while maintaining structural integrity and user safety, addressing the editor's concerns regarding clarity of the operating principle and the associated thermal risk.

2.2. Design Requirements and Considerations

The incinerator was designed under three primary requirements: safety, accessibility, and reproducibility. Safety was prioritized by ensuring the complete destruction of metallic filiform needles without releasing hazardous residues, in line with international biomedical device regulations [17,18]. Accessibility was addressed through the use of low-cost and commercially available materials, while reproducibility was ensured by employing open-source design tools and releasing digital files as Supplementary Materials.

The requirements were defined based on field surveys with acupuncture and physiotherapy practitioners, a review of existing needle disposal devices, and regulatory frameworks [19,20]. A Saaty analytic hierarchy process (AHP) [21] confirmed that safety, cost-efficiency, and ergonomic usability were the highest-ranked parameters guiding the design. Ergonomics was also considered, ensuring a compact structure that could fit in small clinical spaces and reduce operator errors. Beyond the functional requirements, the development process incorporated an engineering-oriented evaluation of critical design parameters associated with operational performance, safety, manufacturability, and user interaction. Parameters such as electrode spacing, insertion port diameter, transformer output current, enclosure dimensions, ventilation geometry, and material selection were iteratively evaluated during the prototyping stages to achieve an appropriate balance between thermal efficiency, portability, structural integrity, and safe operation.

From an industrial design engineering perspective, these parameters directly influenced the interaction between the user and the device, as well as the effectiveness of the localized Joule-heating process used for needle degradation. Consequently, the final prototype configuration was not only defined by aesthetic considerations but also by thermal, ergonomic, electrical, and manufacturability constraints.

To guide the design process, a set of functional, ergonomic, and regulatory requirements were defined, based on user needs, international standards, and technical feasibility. Table 1 summarizes the final design requirements, linking each need with the corresponding design solution.

Description of the hardware with a rationalization of the basic design decisions made. Advantages and disadvantages compared to alternatives. Give a broad overview of the parts required and an estimation of the individual costs of the main parts.

Table 1. The final design requirements and design solutions.

Value	Scope	Requirement	User	Solution
Usability	Easy operation and minimization of errors	Intuitive interface, indicators, ergonomic opening (Ø max. 1.6 mm)	Direct and indirect users	Labeled power buttons, insertion slot, descriptive instructions on casing
Portability	Compact size, lightweight for home/clinic use	Max. 230 × 150 × 95 mm, ≤2 kg	Direct and indirect users	Compact casing, removable tray, ergonomic dimensions (P50 female hand)
Functionality	Efficient incineration of needles	Destroy in 3–5 s at ~800 °C	Direct users	Copper plates as electrodes, transformer 5 V–10 A
Capacity	Minimum 5–20 needles/session	One-by-one incineration	Direct and indirect users	Opening Ø 1.6 mm, waste collector 80 × 75 × 40 mm
Safety	Compliance with IEC 60601-1	Avoid burns and infection risk	Direct and indirect users	Thermal insulation, fuse, enclosed wiring, ventilation slots, rubber feet
Materials	Resistance to high T°, corrosion, chemicals	ABS casing (3D printed), structural metal parts	Direct and indirect users	ABS plastic, stainless steel parts
Economic feasibility	Competitive price	≤USD 300/unit	All user types	Standard components, additive manufacturing
Legal compliance	ARCSA 0023-2016, medical device regulations	Safe biomedical device classification	All user types	User manual, primary/secondary packaging

2.3. Conceptual Design

Several design alternatives were proposed and evaluated according to criteria such as manufacturability, material resistance, ergonomics, and cost-effectiveness. The selected configuration consisted of a compact chamber with a direct resistive heating element, designed to incinerate one or several needles in less than one minute [22]. During the conceptual development phase, multiple design alternatives were compared, considering not only aesthetic and ergonomic criteria but also thermal dissipation behavior, electrical safety, manufacturability through additive manufacturing, and stability of the needle-electrode interaction. Preliminary prototyping revealed that excessive enclosure compactness increased localized heat accumulation near the upper housing, while larger internal volumes reduced portability and increased fabrication time. Similarly, the electrode alignment and insertion pathway were progressively refined to improve electrical contact stability during needle insertion. Small variations in electrode separation affected the concentration of localized heating and influenced the consistency of the degradation process. These observations guided the selection of the final configuration adopted in the prototype.

Three aesthetic approaches were explored: futurist, Braun-inspired, and medical line (see Figure 1). The medical line was prioritized due to its ergonomic appeal and neutral appearance. Safety measures include electrical insulation, a protective fuse, and IEC 60601-1 [23] compliance for electromechanical medical equipment. Figure 2 presents the updated schematic diagram of the system, including the needle insertion pathway, the copper electrode interface, the 5 V–10 A transformer, the electrical circuit closure mechanism, and the ventilation and safety elements.

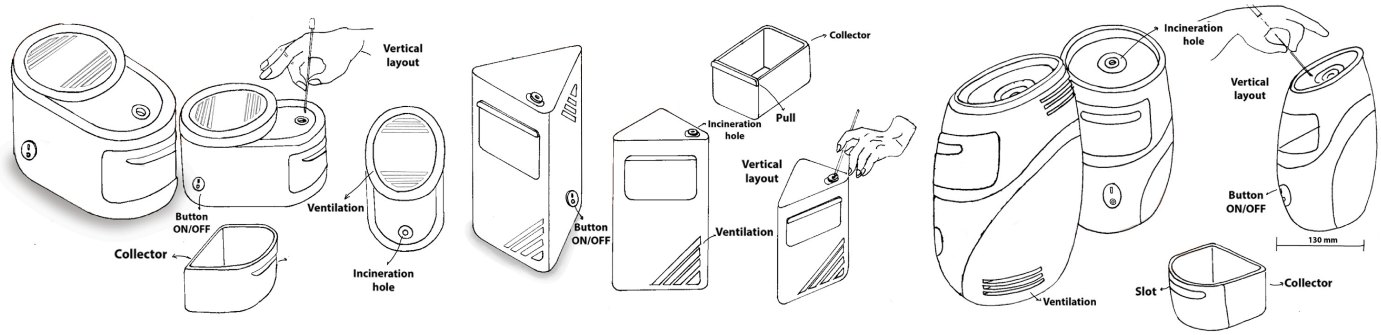

Figure 1. Aesthetic approaches.

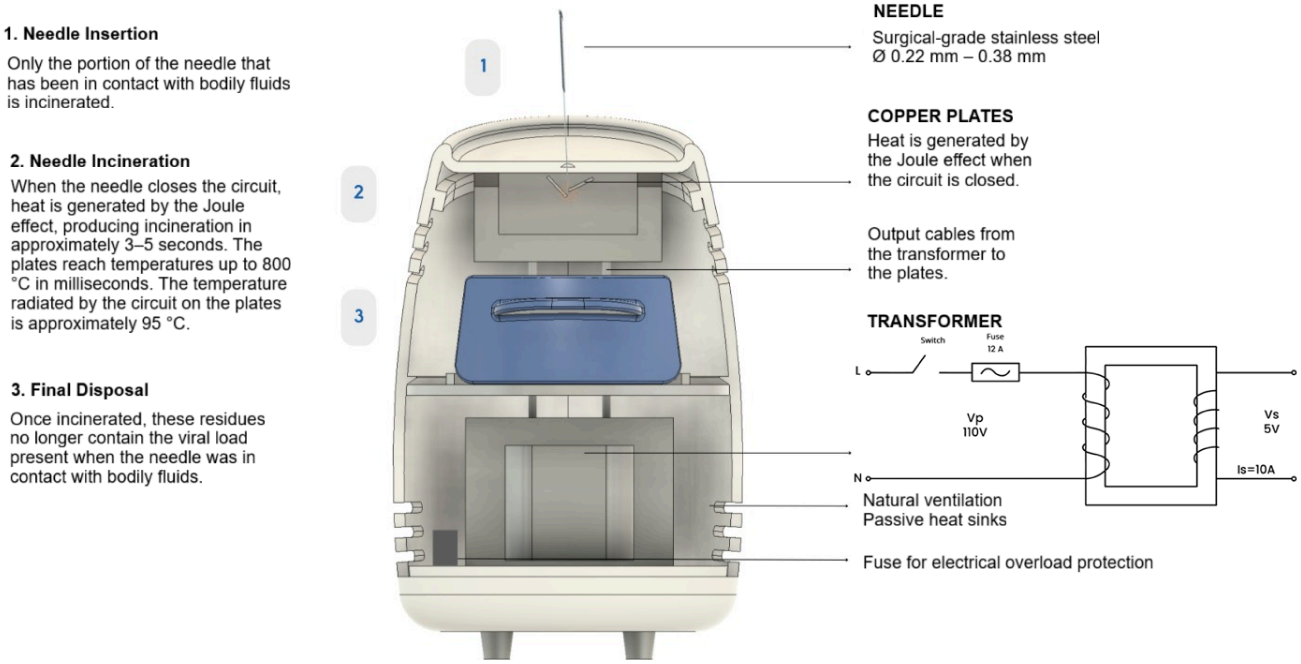

Figure 2. Diagram of the equipment.

2.4. Detailed Design

The final design of the open-source electric needle incinerator integrates structural, electrical, and safety elements developed through iterative prototyping and user-centered adjustments. The external casing was designed in CAD software SolidWorks 2021 and optimized for additive manufacturing [24]. An exploded view of the CAD model illustrates the modular components (see Figures 3 and 4): top cover with insertion slot, internal mechanism support, removable tray, structural body, cable outlet cap, and base with anti-slip supports. This modularity enables straightforward assembly, repair, and replacement of damaged parts without specialized tools.

Material selection was guided by durability, cost, and compatibility with 3D printing. The casing was fabricated using ABS filament, chosen for its thermal resistance, impact strength, and widespread availability. Flexible components, including the removable tray and minor fittings, were printed in TPU (Shore 93A) to improve flexibility and resistance to repeated handling. Internal metallic components such as copper plates withstand the short-duration localized heating produced during the Joule-heating incineration process and resist corrosion under operating conditions.

Material selection also involved thermal and structural considerations associated with the localized heating process. ABS was selected as the primary enclosure material due to its favorable balance between manufacturability, dimensional stability, impact resistance,

and thermal tolerance under short-duration heating conditions. Preliminary evaluations indicated that the combination of passive ventilation slots, thermal separation between the heating chamber and enclosure walls, and short activation cycles effectively limited external temperature accumulation. The dimensions of the insertion port and the positioning of the copper electrodes were additionally adjusted to ensure compatibility with commonly used filiform needles while minimizing unintended electrical arcing and unstable contact during operation. These geometric parameters directly influenced the repeatability and reliability of the needle degradation process.

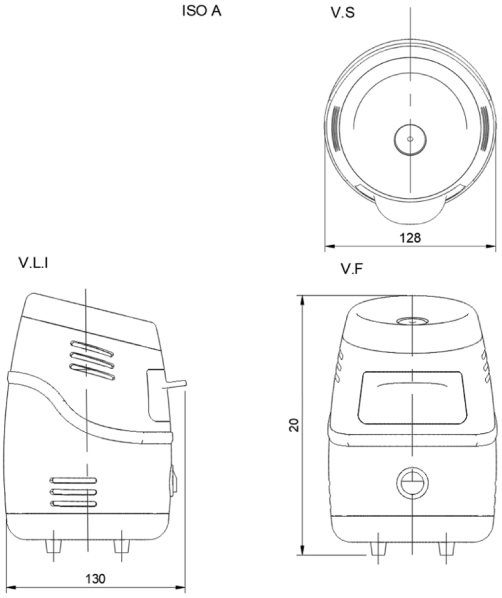

Figure 3. 2D drawing with main dimensions.

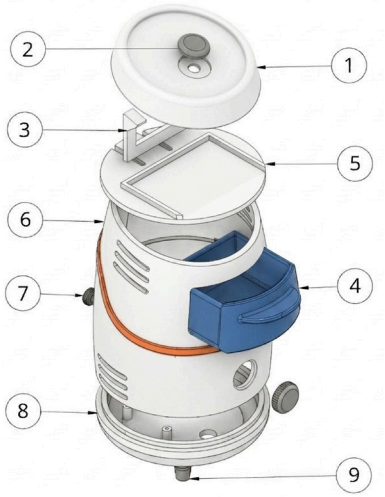

Figure 4. Exploded view CAD breakdown: 1. cover; 2. hole cover; 3. mechanism support; 4. drawer; 5. drawer support; 6. body; 7. cable outlet cap; 8. base; 9. mounting support.

The heating system consists of two copper electrodes connected to a low-voltage, high-current transformer rated at 5–10 A, where the needle closes the circuit and heats up by the Joule effect. Electrical safety was ensured with insulated wiring, a fuse for overload protection, and compliance with IEC 60601-1 [23] standards for electromechanical medical devices. Ventilation slots were incorporated into the casing to prevent overheating, while a thermal barrier was added between the heating chamber and external surfaces to maintain user safety.

A removable ash tray (80 × 75 × 40 mm) allows safe collection of residues, minimizing contamination risks and enabling proper waste disposal in accordance with local biomedical regulations (e.g., ARCSA 0023-2016). Ergonomic criteria were embedded in the detailed design: the needle insertion slot (Ø 1.6 mm) ensures compatibility with the most common filiform needle diameters (0.35–1.6 mm), while compact overall dimensions (230 × 150 × 95 mm, ≤2 kg) guarantee portability and ease of use in outpatient clinics (see Figure 5).

Figure 5. Product in relation to the user.

The bill of materials (BOM) (Table 2) consolidates all structural, electronic, and protective components, with an itemized cost analysis. Total fabrication cost was estimated at 199.3 USD, including 123.5 USD in materials and 75.8 USD in labor. Compared to commercial devices, which range between 300 and 400 USD, the proposed prototype demonstrates significant economic feasibility, making it accessible to clinics, educational laboratories, and practitioners in low-resource environments.

Table 2. Costs associated with the prototype.

Component	Material/Specification	Quantity	Unit Cost (USD)	Total (USD)
Structure	ABS Filament, 1.75 mm, white (1 kg ≈ 335 m)	1	22.5	22.5
Mechanism	Transformer 220 V–110 V to 5 V–10 A	1	40.0	40.0
	Copper plates	1	10.0	10.0
	Switch ON/OFF, 220 V	1	2.0	2.0
	AWG 16–18 wiring	1	3.0	3.0
Protection	Basic fixings, Thermal separation components (3D-printed spacers). Internal support elements	1	5.0	5.0
	TPU Filament 93A, black, 1.75 mm (1 kg ≈ 330 m)	1	33.0	33.0
	Primary packaging (fabric case, 0.3 g)	1	7.0	7.0

Table 2. *Cont.*

Component	Material/Specification	Quantity	Unit Cost (USD)	Total (USD)
Finishing	User manual, 300 g paper	1	1.0	1.0
Subtotal Materials				123.5
Labor	3D printing (machine time)		65.0	65.0
	Assembly (glue)		0.5	0.5
	Sanding (sandpaper)		0.3	0.3
	Welding (solder)		10.0	10.0
Subtotal Labor				75.8
Total Prototype Cost				199.3

Note: costs are related to Ecuadorian region.

2.5. Bill of Material (BOM)

A detailed bill of materials was prepared, including the main structural, electrical, and protective components. Table 2 summarizes the costs associated with the prototype, covering both materials and labor.

2.6. Cost Analysis

The economic feasibility of the proposed prototype was evaluated by analyzing the total cost of materials and labor. The complete device can be built for approximately 199 USD, including 3D-printed parts, electrical components, and assembly. This represents a substantial reduction compared to commercial needle incinerators, which are typically priced in the range of 300–400 USD depending on capacity and brand.

This cost difference highlights the accessibility of the open-source design, making it particularly suitable for small outpatient clinics, educational institutions, and low-resource environments. By using standard components and additive manufacturing, the prototype avoids the need for specialized molds or proprietary spare parts, which further reduces long-term expenses. Beyond the direct economic comparison, the main advantage of the proposed system lies in its open-source and reproducible nature. Unlike proprietary commercial devices, the present design provides unrestricted access to CAD models, STL files, assembly procedures, and component specifications, facilitating local manufacturing, repair, customization, and future adaptation.

From a manufacturing perspective, the proposed design also presents favorable scalability potential. Production of multiple units could further reduce fabrication costs through batch additive manufacturing, bulk acquisition of electronic components, and standardized assembly procedures. Additionally, a future transition toward injection-molded enclosure components could significantly decrease manufacturing time and unit cost for medium-scale production scenarios.

Additionally, the use of additive manufacturing eliminates the need for specialized tooling or proprietary replacement parts, which may reduce long-term maintenance costs and improve accessibility in low-resource environments and educational contexts.

The scalability considerations were additionally supported by prior industrial design evaluation methodologies, including material comparison matrices, Saaty multi-criteria prioritization, manufacturability assessment, and prototype selection through Pugh matrices during the development process.

3. Build Instructions

3.1. Tools and Equipment Required

To ensure reproducibility, only commonly available tools were considered. The fabrication process requires the following:

- 3D printer (FDM technology) with a 0.4 mm nozzle, compatible with ABS and TPU filaments.
- Soldering iron (30–60 W) and solder wire for electronic connections.
- Basic hand tools: screwdrivers, pliers, utility knife, and clamps.
- Finishing tools: fine sandpaper (P400-P800) for smoothing printed parts.
- Personal protective equipment (PPE): insulated gloves, protective glasses, and a mask to ensure safe handling during assembly.

3.2. Component Manufacturing—3D-Printed Parts

3.2.1. 3D-Printed Structural Parts

The structural components of the device were fabricated using fused-filament deposition (FFD) with 1.75 mm ABS filament. ABS was selected due to its mechanical stability, ease of printing, and adequate thermal resistance for short-duration exposure associated with needle incineration. All CAD models were developed in SolidWorks 2021 and exported as STL files for direct fabrication.

The following printed parts compose the external housing and internal supports:

- Main body shell (ABS)—protects the user and houses all internal components.
- Top cover with insertion port (ABS)—guides the needle toward the copper electrodes, ensuring proper alignment during operation.
- Internal electrode support bracket (ABS)—maintains a fixed separation between the copper plates and provides mechanical stability.
- Base plate (ABS)—secure the transformer and internal wiring.
- Ash collection tray (ABS)—removable container that collects residues from the incinerated needles.

All parts were printed using a layer height of 0.2 mm, 20–30% infill, and four perimeters. These settings ensured adequate rigidity while minimizing print time and material usage.

3.2.2. Copper Electrodes

Two copper contact plates serve as the electrical interface for the incineration process. Copper was selected due to its high electrical conductivity and stable performance under short-duration, low-voltage heating cycles. The plates are mounted on the 3D-printed internal support bracket and aligned with the needle insertion port. When the user inserts a needle, its metallic shaft bridges the gap between the plates, closing the circuit. The low-voltage, high-current discharge through the needle produces rapid Joule heating, resulting in localized incineration.

3.2.3. Electrical Components

The electrical system operates at low voltage to ensure user safety and follows the configuration validated in the design analysis. The components include the following:

- Step-down transformer (110 V $\rightarrow$ 5 V, 50 W). Supplies a high-current output ($\approx$10 A) required to achieve rapid Joule heating through the needle.
- Power switch with indicator light. Provides user control and visual confirmation of activation.

- Electrical wiring (AWG 16–18 insulated copper wire). Used for all internal low-voltage connections.
- Miniature fuse (≈30 A). Connected in series with the transformer output to protect the device from accidental short circuits or prolonged activated.
- Screw terminals. Facilitate safe, detachable connections between the transformer, power switch, and copper plates.

All components are arranged on the printed base plate, ensuring adequate spacing and preventing accidental contact with conductive elements.

3.2.4. Ventilation and Thermal Behavior

The device relies on passive ventilation slots integrated into the main body. No fans, forced-air cooling, or metallic thermal chambers are included, as the heating is localized briefly and confined to the needle. As a result, the external ABS surfaces remain within safe operating temperatures (34–42 °C), consistent with the material's thermal limits.

3.3. Assembly Procedure

The assembly process integrates the 3D-printed components, copper electrodes, and low-voltage electrical elements into a compact and functional device. Each step follows a modular that facilitates reproducibility and maintenance.

Step 1—Preparing the Printed Components

After fabrication, each 3D-printed component (main body shell, top cover, electrode support bracket, base plate, and ash collection tray) is cleaned, lightly sanded if necessary, and checked for proper fit. Threaded brass inserts may be embedded into the ABS parts using a soldering iron to ensure screw attachment during assembly.

Step 2—Installing the Copper Electrodes

The two copper contact plates are mounted onto the internal electrode support bracket. Screws or clamping fixtures secure the plates to maintain a fixed separation distance, aligned with the insertion port and providing stable contact surfaces for Joule heating. The assembled bracket is then inserted into the main body shell, ensuring that the copper plates align perfectly with the top cover's needle guide.

Step 3—Mounting the Transformer and Electrical System

The low-voltage transformer (110 V to 5 V, 50 W) is fixed onto the printed base plate using screws or zip-tie anchors integrated into the design. The power switch and indicator light are installed in the designated mounting points.

Internal wiring is arranged as follows:

- AC input—power switch;
- Power switch output to transformer primary;
- Transformer secondary (5 V, high current)—fuse;
- Fuse—copper electrodes (via screw terminals and AWG16–18 wiring).

All connections are protected using insulated crimp terminals and heat-shrink tubing to prevent accidental contact.

Step 4—Inserting the Ash Tray and Aligning the Upper Housing

The removable ash collection tray is slid into its compartment beneath the electrode assembly. The top cover is placed over the main body shell and secured using screws. Alignment of the insertion port with the electrode plates is verified again to ensure proper functioning.

Step 5—Final Closure and Safety Check

Before final closure, the internal wiring is inspected to confirm:

- No exposed conductive parts;
- Stable soldered or screw-terminal connections;
- Sufficient clearance between live elements and printed walls;
- Unobstructed ventilation paths.

Once verified, the device is fully closed (see Figure 6) and tested without a needle to ensure the electrical path remains open until a needle bridges the electrodes. Functional testing proceeds as described in Section 5.

Figure 6. Final assembly.

3.4. Estimated Time and Difficulty

Printing time: ~10–12 h (depending on printer settings).
Assembly time: ~2–3 h.
Total build time: ~15 h.
Skill level required: Intermediate (basic knowledge of 3D printing and electrical connections).

4. Operating Instructions

Principal parts (see Figure 7).

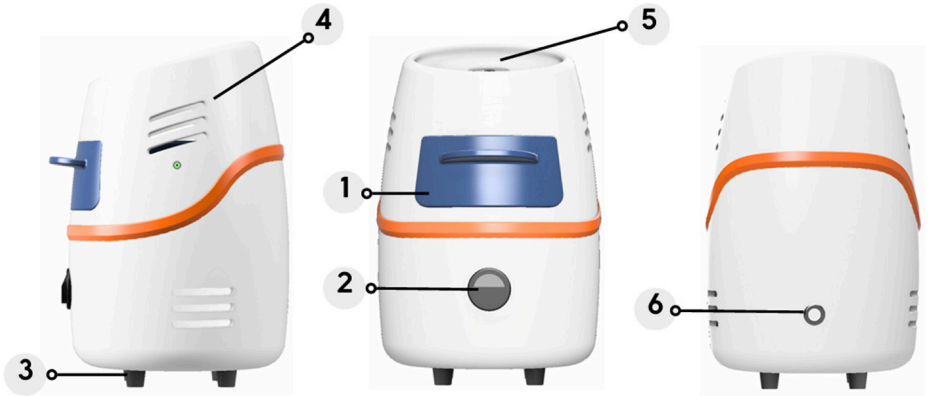

Figure 7. Parts of the incinerator: 1. waste collection tray; 2. power ON/OFF button; 3. support brackets; 4. ventilation outlets; 5. needle insertion port; 6. power supply cable outlet.

Principal instructions:
The device is designed for simple and safe operation in outpatient therapeutic contexts such as acupuncture, dry needling, or physiotherapy. The interface relies on a

single activation switch and an insertion port that guides the needle directly toward the copper electrodes.

Step 1—Powering the Device

- Connect the AC power cord to a standard 110 V outlet.
- Switch the device ON using the illuminated main power switch.
- The indicator light confirms that the circuit is energized.
- No current flows through the electrodes until a metallic needle bridge them, ensuring intrinsic safety.

Step 2—Needle Insertion

- Hold the used fine needle by its plastic handle.
- Insert the metallic shaft through the top guide and into the insertion port.
- As the needle advances, it contacts both copper plates.
- Once contact is established, the needle closes the low-voltage circuit between the two plates.

This design ensures that the needle itself acts as the conductive bridge, and heating is restricted to the metal segment exposed to the electrodes.

Step 3—Incineration Process

Once the circuit is closed, the following take place:

- A 5 V high-current discharge (≈10 A) flows through the needle.
- Due to the Joule heating, the metal segment rapidly reaches incineration temperature.
- The exposed portion of the needle oxidizes and fragments within approximately 3–5 s.
- The heating is localized and short-duration, preventing heat transfer to the external ABS enclosure.

The process is complete when the metallic segment detaches or visibly disintegrates.

Step 4—Residue Collection (see Figure 8)

Figure 8. Sequence illustrating the needle insertion and incineration process, showing alignment with electrodes and ashtray deposition.

- Any remaining ash or metallic debris falls directly into the removable ash collection tray located beneath the electrodes.

- The tray can be extracted manually for disposal following clinical waste protocols.
- The design prevents accidental contact with hot components during extraction.

Step 5—Device Shutdown

- After disposing of the residue, switch the device OFF.
- Disconnect the power cord if the device will not be used for an extended period.
- Allow a brief cooling period (15–20 s), although external components remain within safe-touch temperature ranges during operation.

Operational Safety Notes

- The device operates at low voltage, ensuring user protection even during accidental contact with the housing.
- No heating occurs unless a needle bridges the electrodes.
- Passive ventilation slots prevent heat buildup inside the enclosure.
- The 30 A fuse protects against prolonged activation or accidental short circuits.

These features align with the safety criteria established during the design phase and validated experimentally in Section 5.

Safety Precautions

- Do not insert more than one needle at a time to avoid malfunction.
- Do not operate on flammable surfaces.
- Use only under adult supervision in a clinical or therapeutic environment.
- Avoid direct contact with the heating plates; surfaces may remain hot after
- operation.
- Ensure that the fuse and protective casing remain intact to prevent electrical hazards.

Maintenance

- Periodically check the electrical wiring and switch for signs of wear.
- Clean the casing with a dry cloth; avoid water contact.
- Replace the fuse if the device does not power on after overheating protection.
- Expected lifespan: 5–7 years, with minimal maintenance.

5. Validation

5.1. Functional Testing

The prototype was tested under typical operating conditions to verify its performance. Needles with diameters ranging from 0.35 mm to 1.6 mm were incinerated individually. Each incineration cycle lasted approximately 3–5 s, with the device reaching operational temperatures of ~800 °C. The ~800 °C value corresponds to the approximate oxidation temperature of stainless steel under Joule heating; however, this does not represent the temperature of the copper electrode surfaces, which remain considerably lower due to the short duty cycle and localized heating restricted to the needle.

5.2. Capacity Test

The device successfully processed 5–20 needles in a single session, corresponding to the average number used during acupuncture or dry needling therapy (Table 3). No performance degradation was observed within this range.

Table 3. Mean time relative to needle count.

Needles per Session	Approx. Total Time (s)	Approx. Total Time (min)
5	17.5	0.29
10	35.0	0.58
15	52.5	0.88
20	70.0	1.17

5.3. Safety Validation

The external casing remained below safe-touch temperature thresholds due to proper thermal insulation. The ventilation slots prevented overheating during continuous operations. The fuse provided electrical protection, activating correctly under overload conditions. In Figure 9, the use of the product in a clinic is shown.

Figure 9. Product validation.

The safety strategy adopted during the development process considered the principal operational risks associated with electrical contact, localized heating, and thermal accumulation inside the enclosure. These risks were mitigated through low-voltage operation, insulated internal wiring, fuse-based overload protection, passive ventilation, and thermal separation between the heating chamber and the external ABS casing.

The safety-oriented configuration of the prototype was additionally supported by industrial design evaluation methodologies, including ergonomic assessment, material selection analysis, and thermal behavior considerations performed during the conceptual and detailed design stages. These evaluations contributed to minimizing user exposure to high-temperature regions and improving operational stability during repeated activation cycles.

Safety validation was approached through repeated short-cycle operational testing focused on the principal risks associated with localized Joule heating, including external heat accumulation, accidental user contact with conductive components, and enclosure thermal stability. The combined safety measures ensured stable operation without observable structural deformation or unsafe external surface temperatures during the evaluated operating conditions.

5.4. Comparative Analysis

Commercial portable needle incinerators typically range between 300 and 400 USD depending on capacity, portability, and safety features [25–27], while the proposed prototype was built for approximately 199 USD. Despite the lower cost, the device achieved compara-

ble incineration efficiency in terms of time and reliability, demonstrating its potential as an accessible open-source alternative for outpatient clinics and educational settings.

The validation results demonstrated that the open-source electric needle incinerator achieves performance comparable to commercial devices while reducing fabrication costs by approximately 35–45% lower. This outcome is particularly relevant in low-resource clinical settings, where high equipment costs often prevent the adoption of safe biomedical waste management practices. The device's ability to reliably incinerate needles in 3–5 s matches the efficiency of proprietary systems, confirming its technical feasibility.

The proposed device aligns with previous studies emphasizing the importance of point-of-use needle destruction systems for reducing occupational exposure and preventing the reuse of contaminated sharps [28,29]. Unlike large-scale plasma-based biomedical waste treatment technologies, the present approach focuses on localized low-power Joule heating, prioritizing portability, accessibility, low manufacturing cost, and ease of implementation in outpatient therapeutic environments. This positioning reinforces the relevance of compact electric needle incinerators as practical alternatives for decentralized biomedical waste management in low-resource clinical settings.

From an occupational safety perspective, the integration of thermal insulation, fuse protection, and compliance with IEC 60601-1 standards ensures secure operation even under continuous use [23]. This aligns with recommendations from the World Health Organization (WHO) regarding the importance of safe sharps disposal to minimize risks of hepatitis B, hepatitis C, and HIV transmission. Moreover, by designing a removable ashtray and incorporating clear labeling, the prototype addresses critical aspects of biosecurity and user ergonomics, often neglected in improvised disposal practices observed in small clinics.

A major advantage of the proposed design is its reproducibility and open-source nature. Unlike commercial incinerators that provide no access to technical documentation, this work releases all CAD models, STL files, and assembly instructions, allowing replication and adaptation by practitioners, researchers, and educators. This openness aligns with the global movement towards open hardware in healthcare, fostering collaborative improvements, reducing dependence on proprietary supply chains, and expanding accessibility to innovative solutions.

Despite its strengths, some limitations must be acknowledged. First, the device is currently restricted to single-needle incineration, which, although adequate for most therapeutic sessions (5–20 needles), may limit its application in high-throughput clinical environments. Second, its operation depends on stable electrical supply, which may present challenges in rural or off-grid contexts. Additionally, while safety validation confirmed external casing stability, further long-term endurance testing is required to evaluate mechanical wear of the electrodes and thermal stability of 3D-printed parts.

Future developments may focus on automating the feeding mechanism for multi-needle incineration, integrating temperature sensors and IoT-based monitoring to track device usage and performance in real time. Optimizing energy consumption through advanced thermal control strategies could further enhance sustainability, especially in regions with limited resources. Expanding usability to other biomedical sharps (e.g., lancets, micro-needles) also represents a potential research direction.

Overall, this discussion situates the proposed device as a low-cost, safe, and reproducible alternative that addresses critical gaps in current biomedical waste management. Its open-source documentation strengthens its impact, ensuring that the solution can be replicated, scaled, and improved by the global community, particularly in contexts where safe disposal of sharps remains a pressing challenge.

The relevance of the proposed hardware is not limited to fabrication cost reduction alone. Its open-source architecture enables decentralized production, rapid customization,

and collaborative improvement by researchers, educators, and healthcare practitioners. This characteristic represents a significant advantage compared to closed commercial systems that restrict repairability, adaptation, and technological transfer.

From an environmental perspective, localized point-of-use needle destruction may additionally contribute to reducing intermediate transport, handling, and storage requirements associated with centralized biomedical waste management processes. Although the present study does not include a complete life-cycle assessment, the proposed approach may support safer and more decentralized waste handling strategies for outpatient therapeutic environments.

5.5. Parametric Thermal–Electrical Analysis

To complement the functional validation of the prototype, a parametric thermal–electrical analysis was conducted to evaluate the influence of key operational and geometric parameters on the needle degradation process. The analysis focused on variables directly associated with Joule-heating performance, including needle diameter, electrical current intensity, electrode spacing, and thermal dissipation through the enclosure.

The objective of this analysis was not to optimize the system through advanced numerical modeling, but rather to experimentally characterize the influence of the main design parameters governing operational stability, thermal behavior, and degradation efficiency within the proposed open-source hardware configuration.

The experimental characterization revealed a direct relationship between needle diameter and degradation time (see Table 4). Needles with larger diameters required longer exposure times due to the increased metallic cross-sectional area, which reduced localized current density and consequently decreased the Joule-heating rate. For smaller diameters (0.35–0.50 mm), the thermal energy was concentrated rapidly at the electrode interface, producing fast oxidation and fragmentation within approximately 3 s. In contrast, larger diameters (1.20–1.60 mm) exhibited slower degradation behavior and occasional residual fragments, suggesting increased thermal diffusion along the metallic shaft.

Table 4. Experimental thermal–electrical characterization of the prototype.

Needle Diameter (mm)	Electrode Gap (mm)	Current (A)	Mean Degradation Time (s)	Observed Behavior
0.35	1.0	8.1	2.8 ± 0.2	Rapid oxidation and fragmentation
0.50	1.0	8.4	3.1 ± 0.3	Stable localized heating
0.80	1.2	8.8	3.7 ± 0.4	Uniform degradation
1.20	1.5	9.4	4.4 ± 0.5	Partial metallic residue
1.60	1.5	10.0	5.1 ± 0.6	Slower fragmentation behavior

Electrode spacing also influenced operational stability. Smaller gaps promoted faster thermal concentration and improved electrical contact consistency; however, excessively reduced separation distances increased the probability of unintended electrical arcing between the copper plates. Based on iterative prototyping and experimental observations, an electrode spacing between 1.0 and 1.5 mm provided the best compromise between thermal efficiency, operational repeatability, and user safety. Additionally, the combination of passive ventilation and short-duration activation cycles prevented excessive thermal accumulation within the ABS enclosure. External surface temperatures remained below critical thermal deformation thresholds associated with ABS materials, supporting the suitability of the selected enclosure configuration for repeated short-cycle operation.

These findings demonstrate that the final prototype configuration was strongly influenced by engineering-oriented evaluation of thermal, electrical, ergonomic, and manufacturability parameters rather than solely aesthetic considerations.

6. Conclusions

This work presented the design, construction, and validation of an open-source electric needle incinerator intended for use in acupuncture and dry needling therapies. The device was developed with a focus on safety, affordability, and reproducibility, integrating 3D-printed components, standard electronic parts, and clear build instructions.

Validation tests demonstrated that the prototype is capable of incinerating individual needles in 3–5 s, processing a typical session of 5–20 needles without performance degradation. The device ensures occupational safety through adequate thermal insulation, protective casing, and compliance with relevant standards.

One of the most significant advantages of the proposed design is its economic feasibility: with a fabrication cost of approximately 199 USD, compared to commercial devices priced between 300 and 400 USD. This makes the prototype a practical solution for outpatient clinics, academic laboratories, and low-resource environments.

By making the design files openly available, this contribution strengthens the open hardware community, enabling replication, adaptation, and future improvements. Potential areas for further development include automation of the incineration process, integration of temperature sensors, and optimization of energy consumption. Give a general discussion if the device fulfills the expected performance.

Supplementary Materials: The STL models presented correspond to the final prototype design and are provided to ensure reproducibility and facilitate future adaptations by other researchers and practitioners [30]. The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/hardware4020012/s1.

Name	Type	Description
S1	Top Cover (.stl)	Upper enclosure of the device, protecting the inner mechanism.
S2	Main Body (.stl)	Core housing that integrates all electrical and mechanical parts.
S3	Base (.stl)	Structural foundation of the prototype, designed to keep the assembly stable.
S4	Needle Insertion Port (.stl)	Small precision opening that guides the needle directly to the heating chamber.
S5	Drawer (.stl)	A detachable tray used to collect ashes and metallic residues after the incineration cycle.
S6	Drawer Base 1 (.stl)	The first lower platform that supports the drawer maintains its correct position.
S7	Drawer Base 2 (.stl)	Secondary base element reinforcing the drawer structure and ensuring smooth insertion.
S8	Mechanism Plate Support (.stl)	Internal bracket that secures the heating plates and electrical components in place.
S9	Cable Inlet (.stl)	Entry port for the main power cable.
S10	Feet (.stl)	Non-slip supports are attached to the bottom of the device to reduce vibration. EMSAMBLE.
S11	Arthur (.stl)	Complete assembly of the proposed prototype.

Note: For each design file listed in the summary table above, include a short description of the file.

Author Contributions: Conceptualization, D.B.-D. and Y.A.; methodology, D.B.-D. and Y.A.; software, Y.A. and A.R.; validation, D.B.-D. and A.R.; formal analysis, A.R. and T.F.-R.; investigation, D.B.-D. and Y.A.; resources, Y.A.; data curation, T.F.-R.; writing—original draft preparation, T.F.-R.; writing—review and editing, A.R. and T.F.-R.; visualization, T.F.-R.; supervision, A.R.; project administration, D.B.-D. and A.R.; funding acquisition, not applicable. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding. The study was fully supported by the authors' own financial resources. No funds, grants, or other support were received from any public, commercial, or not-for-profit sectors.

Institutional Review Board Statement: Not applicable. This study did not involve humans or animals.

Informed Consent Statement: Not applicable. This study did not involve humans.

Data Availability Statement: The original contributions presented in this study are included in the article and supplementary materials. Further inquiries will be made available by the authors on reasonable request.

Acknowledgments: The authors gratefully acknowledge the laboratories of the Faculty of Engineering and Applied Sciences, School of Industrial Design Engineering, at the Universidad Central del Ecuador (UCE) for providing the technical support and facilities essential to the completion of this study. During the preparation of this manuscript, the authors used ChatGPT Plus for the purposes of improving sentence structure, readability, and grammatical corrections during the revision process. No AI tools were used for generating scientific content, research data, results, analysis, interpretations, or conclusions. All scientific contributions, technical development, and intellectual content of the manuscript were fully developed by the authors. The authors have reviewed and edited the output and take full responsibility for the content of this publication.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Ajay, S.V.; Prathish, K.P. Dioxins emissions from bio-medical waste incineration: A systematic review on emission factors, inventories, trends and health risk studies. *J. Hazard. Mater.* **2024**, *465*, 13384. [CrossRef] [PubMed]
2. Lan, D.-Y.; Zhang, H.; Wu, T.-W.; Lü, F.; Shao, L.-M.; He, P.-J. Repercussions of clinical waste co-incineration in municipal solid waste incinerator during COVID-19 pandemic. *J. Hazard. Mater.* **2022**, *423*, 127144. [CrossRef] [PubMed]
3. Marín, L. Plan Operativo Para Manejo de Desechos Hospitalarios de la Asociacion de Servicios de Limpieza Pureza Total Asoserliput. 2021. Available online: https://portal.compraspublicas.gob.ec/sercop/wp-content/uploads/2023/12/Plan-de-Manejo-Desechos-ASOSERLIPUT-Sept-2021-signed-signed.pdf (accessed on 11 March 2024).
4. Sandoval, N. Diagnóstico del Proceso de Recolección Tratamiento y Disposición Final de Desechos de los Servicios de Salud del Hospital IESS Machala. Master's Thesis, Universidad Técnica de Machala, Machala, Ecuador, 2017. Available online: http://repositorio.utmachala.edu.ec/handle/48000/10386 (accessed on 17 October 2024).
5. Lao, L. Acupuncture techniques and devices. *J. Altern. Complement. Med.* **1996**, *2*, 23–25. [CrossRef] [PubMed]
6. Izquierdo, M.M.I. Análisis de la Gestión de los Desechos Peligrosos y Especiales Domiciliarios en el Distrito Metropolitano de Quito. 2021. Available online: https://repositorio.uasb.edu.ec/bitstream/10644/8177/1/T3562-MCCNA-Izquierdo-Analisis.pdf (accessed on 23 November 2023).
7. Moreno, J.M. Diseño e Implementación de un Sistema de Manejo de Residuos Peligrosos Generados en los Terminales y Depósitos de ep Petroecuador. Master's Thesis, UISEK, Quito, Ecuador, 2011. Available online: https://repositorio.uisek.edu.ec/bitstream/123456789/101/1/Sistema%20de%20Manejo%20de%20Residuos%20Peligrosos%20EP%20PETROECUADOR.pdf (accessed on 9 April 2024).
8. Egbuna, A.Q.; Azeez, T.O.; Ejeta, K.O.; Banigo, A.; Ndubuka, G.I. Design and Fabrication of Needle Burner and Polymer Recycler. *Afr. J. Med. Phys. Biomed. Eng. Sci.* **2020**, *7*, 90–100. Available online: https://www.researchgate.net/publication/348018094_Design_and_fabrication_of_needle_burner_and_polymer_recycler (accessed on 23 November 2023).

9. García-Silvera, E.E.; Meléndez-Mogollón, I.C.; Barahona-Naranjo, R.I.; Álvarez-González, A.R. Impacto en la salud humana de los desechos provenientes en hospitales y posibles estrategias de manejo. *Rev. Conecta Lib.* **2019**, *3*, 24–43.
10. Shaik, S.R.; Mahalingam, A.K.; Palanisamy, M.; Kalita, P.C. Comprehensive review on medical waste incineration. *Int. J. Glob. Warm.* **2022**, *27*, 16. [CrossRef]
11. Morán Anrango, J.H. Incinerador Eléctrico Portátil de Agujas Hipodérmicas Para Casas de Salud. Bachelor's Thesis, Universidad Técnica del Norte, Ibarra, Ecuador, 2017. Available online: https://repositorio.utn.edu.ec/handle/123456789/6542 (accessed on 9 April 2024).
12. Chandra, M.; Bhat, P. Latest Biomedical Waste Management Guidelines. *Int. J. Med. Sci. Curr. Res.* **2023**, *6*, 854–862.
13. El-Amaireh, N.A.A.; Al-Zoubi, H.; Al-Khashman, O.A. Hospital waste incinerator ash: Characteristics, treatment techniques, and applications (A review). *J. Water Health* **2023**, *21*, 1686–1702. [CrossRef] [PubMed]
14. Cai, X.; Du, C. Thermal Plasma Treatment of Medical Waste. *Plasma Chem. Plasma Process.* **2021**, *41*, 1–46. [CrossRef]
15. Wang, T.; Guo, J.; Wang, K.; Liu, L.; Chen, Y. Study on the degradation characteristics of PCDD/Fs using Non-thermal Plasma (NTP) technology in full-scale medical waste incineration. *J. Hazard. Mater.* **2025**, *491*, 137866. [CrossRef] [PubMed]
16. Cano-Franco, J.C.; Álvarez-Láinez, M.L. Proceeding of the Desing Society. In *Integrated Design Methodology: A Proposal for a Scientific Research-Based Design Process for Stimuli-Responsive Products*; Cambridge University: Cambridge, UK, 2023; pp. 2335–2344. [CrossRef]
17. Agencia Nacional de Regulación y Control. Reglamento Gestion Desechos Generados en Establecimientos de Salud. Available online: https://www.controlsanitario.gob.ec/wp-content/uploads/downloads/2019/04/Acuerdo-Ministerial-323_Reglamento-para-la-gesti%C3%B3n-integral-de-los-residuos-y-desechos-generados-en-los-establecimientos-de-salud.pdf (accessed on 14 November 2023).
18. Espinoza, G. ANEXO 3.3—Instructivo Manejo Adecuado de Desechos. 2020. Available online: https://www.unach.edu.ec/wpcontent/Riesgos%20Laborales/PLANES_DE_EMERGENCIA/2020/ANEXO%203.3%20-%20INSTRUCTIVO%20MANEJO%20ADECUADO%20DE%20DESECHOS%20-LIC.%20GABRIELA%20ESPINOZA.pdf (accessed on 17 February 2025).
19. Sutrisno, H.; Meilasari, F. Review: Medical Waste Management for Covid19. *J. Kesehat. Lingkung.* **2020**, *12*, 104–120. [CrossRef]
20. Garrido, R. Acupuntura y Dolor. *Rev. Med. Clin. Condes* **2019**, *30*, 487–493. [CrossRef]
21. Toscano Hurtado, G.B. El Proceso de Análisis Jerárquico (AHP) Como Herramienta Para la Toma de Decisiones en la selección de Proveedores. Bachelor's Thesis, Universidad Nacional Mayor de San Marcos, Lima, Peru, 2005. Available online: https://sisbib.unmsm.edu.pe/BibVirtual/monografias/Basic/toskano_hg/contenido.htm (accessed on 17 February 2025).
22. Ayo Paucar, Y.M. Rediseño de un Incinerador Eléctrico de Agujas de Presión Usadas en Tratamientos de Acupuntura y Punción seca. Bachelor's Thesis, UCE, Quito, Ecuador, 2025. Available online: https://www.dspace.uce.edu.ec/entities/publication/0628d205-5952-4dad-b093-09979300a205 (accessed on 17 February 2025).
23. *IEC 60601*; Medical Electrical Equipment—Part 1: General Requirements for Basic Safety and Essential Performance. International Electrotechnical Commission: Geneva, Switzerland, 2012. Available online: https://webstore.iec.ch/en/publication/2612 (accessed on 9 April 2024).
24. Culmone, C.; Smit, G.; Breedveld, P. Additive manufacturing of medical instruments: A state-of-the-art review. *Addit. Manuf.* **2019**, *27*, 461–473. [CrossRef]
25. Agupunt. Destructores de Agujas y Jeringas—Tienda Oficial Agupunt. Available online: https://tienda.agupunt.com/aparatologia/destructores-de-agujas/?srsltid=AfmBOoo5g-CjsIRBFAG2YXOcs5tVpY4zzG8fRDYsl9sF5vlYqEZ2bjWe (accessed on 13 May 2026).
26. Jampar. Destructores de Aguja Para Laboratorio—Alta Seguridad y Eficiencia. Available online: https://www.jampar.com.pe/c/equipos-laboratorio/destructor-de-aguja/?srsltid=AfmBOoqK9Y69bCr-h9bVMd8WUtNpPDuOT5IUBm8k7TOpd-u2PYv-tJJ9 (accessed on 13 May 2026).
27. Nanjing Poweam Medical Co., Ltd. Ultrasound Scanner Manufacturer, Color Doppler, X-Ray Film Supplier. Available online: https://poweam-medical.en.made-in-china.com/ (accessed on 13 May 2026).
28. Mao, S.; Li, S.; Zhang, Y.; Long, L.; Peng, J.; Cao, Y.; Mao, J.Z.; Qi, X.; Xin, Q.; San, G.; et al. A highly efficient needle-free-injection delivery system for mRNA-LNP vaccination against SARS-CoV-2. *Nano Today* **2023**, *48*, 101730. [CrossRef] [PubMed]
29. Wawale, S.G.; Shabaz, M.; Mehbodniya, A.; Soni, M.; Deb, N.; Elashiri, M.A.; Dwivedi, Y.D.; Naved, M. Biomedical Waste Management Using IoT Tracked and Fuzzy Classified Integrated Technique. *Hum.-Centric Comput. Inf. Sci.* **2022**, *12*, 401–414. [CrossRef]
30. Yu, Z.; Guo, S. A low-cost, wireless, 4-channel EEG measurement system used in virtual reality environments. *HardwareX* **2024**, *17*, e00507. [CrossRef] [PubMed]